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(54) **METHOD AND APPARATUS FOR PRODUCING PARTS BY SELECTIVE SINTERING.**

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DD-A- 0 137 951
DE-A- 2 263 777
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Description

This invention relates to a method and apparatus which uses a directed energy beam to selectively sinter a powder to produce a part. In particular, this invention relates to a computer aided laser apparatus which sequentially sinters a plurality of powder layers to build the desired part in a layer-by-layer fashion.

The economies associated with conventional part production methods are generally related directly to the quantity of parts to be produced and the desired material characteristics of the finished parts. For example, large scale manufacture casting and extrusion techniques are often cost effective, but these production methods are generally unacceptable for small quantities - i.e. replacement parts or prototype production. Many such conventional part production methods require expensive part specific tooling. Even powder metallurgy requires a die for shaping the powder, making powder metallurgy unattractive as a method for producing a small number of parts.

Where only a small number of parts are desired, conventional production methods involving a subtractive machining method are usually used to produce the desired part. In such substractive methods, material is cut away from a starting block of material to produce a more complex shape. Examples of substractive machine tool methods include: milling, drilling, grinding, lathe cutting, flame cutting, electric discharge machine, etc. While such conventional machine tool substractive methods are usually effective in producing the desired part, they are deficient in many respects.

First, such conventional machine tool substractive methods produce a large amount of waste material for disposal. Further, such machine tool methods usually involve a large initial expense for setting up the proper machining protocol and tools. As such, the set-up time is not only expensive, but relies a great deal on human judgment and expertise. These problems are, of course, exacerbated when only a small number of parts are to be produced.

Another difficulty associated with such conventional machining techniques involves tool wear - which not only involves the cost of replacement, but also reduces machining accuracy as the tool wears. Another limit on the accuracy and tolerance of any part produced by conventional machining techniques is the tolerance limits inherent in the particular machine tool. For example, in a conventional milling machin or lathe, th lead scr ws and ways are manufactur d to a certain tol ranc , which limits the tolerances obtainabl in manufacturing a part on the machine tool. Of course, the toleranc s attainabl ar reduced with age f th machine tool.

The final difficulty associated with such conventional machine tool subtractive processes is the difficulty or impossibility of making many part configurations. That is, conventional machining methods are usually best suited for producing symmetrical parts and parts where only the exterior part is machined. However, where a desired part is unusual in shape or has internal features, the machining becomes more difficult and quite often, the part must be divided into segments for production. In many cases, a particular part configuration is not possible because of the limitations imposed upon the tool placement on the part. Thus, the size and configuration of the cutting tool do not permit access of the tool to produce the desired configuration.

There are other machining processes which are additive, for example, plating, cladding, and some welding processes are additive in that material is added to a starting substrate. In recent years, other additive-type machining methods have been developed which use a laser beam to coat or deposit material on a starting article. Examples include U.S. Patent Nos. 4,117,302; 4,474,861; 4,300,474; and 4,323,756. These recent uses of lasers have been primarily limited to adding a coating to a previously machined article. Often such laser coating methods have been employed to achieve certain metallurgic properties obtainable only by such coating methods. Typically, in such laser coating methods the starting article is rotated and the laser directed at a fixed location with the coating material sprayed onto the article so that the laser will melt the coating onto the article.

From DE-A-2 263 777 a method of producing a part is known comprising the steps of depositing a continuous flow of meltable powder onto a matrix, moving the aim of several directed energy beams over the areas of the part to be produced and melting powder being present within the area of the aim of the directed energy beams so that after some time the part is produced.

From DD-A- 137 951 a method is known for direct production of textile structures made of a high polymer substrate having a powder form in the beginning.

From JP-A-59-45089 a laser scanning system is known to perform uniform and stable built up welding with good working efficiency by scanning a flat beltlike filler metal on a base material longitudinally by reflected laser light while scanning continuously said metal back and forth in a transverse direction th reby m lting th filler metal.

US-A-4 247 508 discloses a method and an apparatus acc rding to the preambles of claims 1 and 9.

The probl ms outlined above ar in larg ma-

jor solved by the method and apparatus of the present invention as defined in method claim 1 and apparatus claim 9. The present invention includes a directed energy beam - such as a laser - and is adaptable to produce almost any three dimensional part. The method of the present invention is an additive process, with the powder being dispensed into a target area where the laser selectively sinters the powder to produce a sintered layer. The invention is a layer-wise process in which the layers are joined together until the completed part is formed. The method of the present invention is not limited to a particular type of powder, but rather is adaptable to plastic, metal, polymer, ceramic powders, or composite materials.

Broadly speaking, the apparatus includes a laser or other directed energy source which is selectable for emitting a beam in a target area where the part is produced. A powder dispenser system deposits powder into the target area. A laser control mechanism operates to move the aim of the laser beam and modulates the laser to selectively sinter a layer of powder dispensed into the target area. The control mechanism operates to selectively sinter only the powder disposed within defined boundaries to produce the desired layer of the part. The control mechanism operates the laser to selectively sinter sequential layers of powder, producing a completed part comprising a plurality of layers sintered together. The defined boundaries of each layer correspond to respective cross-sectional regions of the part. Preferably, the control mechanism includes a computer - e.g. a CAD/CAM system - to determine the defined boundaries for each layer. That is, given the overall dimensions and configuration of the part, the computer determines the defined boundaries for each layer and operates the laser control mechanism in accordance with the defined boundaries. Alternatively, the computer can be initially programmed with the defined boundaries of each layer.

In a preferred form, the laser control mechanism includes a mechanism for directing the laser beam in the target area and a mechanism for modulating the laser beam on and off to selectively sinter the powder in the target area. In one embodiment, the directing mechanism operates to move the aim of the laser beam in a continuous raster scan of target area. The modulating mechanism turns the laser beam on and off so that the powder is sintered only when the aim of the laser beam is within the defined boundaries for the particular layer. Alternatively, the directing mechanism aims the laser beam only within the defined boundaries for the particular layer so that the laser beam can be left on continuously to sint r the powder within the defined boundaries for the particular layer.

In a preferred embodiment, th directing m chanism mov s th laser beam in a r petitiv raster scan of the targ t ar a using a pair of mirrors driven by galvonometers. The first mirror reflects the laser beam to the second mirror which reflects the beam into the target area. Shifting movement of the first mirror by its galvonometer shifts the laser beam generally in one direction in the target area. Similarly, shifting movement of the second mirror by its galvonometer shifts the laser beam in the target area in a second direction. Preferably, the mirrors are oriented relative to each other so that the first and second directions are generally perpendicular to each other. Such an arrangement allows for many different types of scanning patterns of the laser beam in the target area, including the raster scan pattern of the preferred embodiment of the present invention.

The method of part production of the present invention includes the steps of depositing a first portion of powder onto a target surface, scanning the aim of a directed energy beam (preferably a laser) over the target surface, and sintering a first layer of the first powder portion on the target surface. The first layer corresponds to a first cross-sectional region of the part. The powder is sintered by operating the directed energy source when the aim of the beam is within the boundaries defining the first layers. A second portion of powder is deposited onto the first sintered layer and the aim of the laser beam scanned over the first sintered layer. A second layer of the second powdered portion is sintered by operating the directed energy source when the aim of the beam is within the boundaries defining the second layer. Sintering of the second layer also joins the first and second layers into a cohesive mass. Successive portions of powder are deposited onto the previously sintered layers, each layer being sintered in turn. In one embodiment, the powder is deposited continuously into the target.

In a preferred embodiment, the laser beam is modulated on and off during the raster scan so that the powder is sintered when the aim of the beam is directed within the boundaries of the particular layer. Preferably, the laser is controlled by a computer; the computer may include a CAD/CAM system, where the computer is given the overall dimensions and configuration of the part to be made and the computer determines the boundaries of each cross-sectional region of the part. Using the determined boundaries, the computer controls the sintering of each layer corresponding to the cross-sectional regions of the part. In an alternative embodiment, the computer is simply programmed with the boundaries of each cross-s ctional region of the part.

Additionally, another embodiment of the pr s nt invention includ s a d vice for distributing the powder as a layer over th targ t ar a or region. Pr f rably, the distributing d vic includ s a drum, a mechanism for moving the drum across the region, and a mechanism for counter-rotating the drum as it is moved across the region. The drum moving mechanism preferably keeps the drum a desired spacing above the region to yield a layer of powder of a desired thickness. The drum is operable when counter-rotated and moved across the region to project powder forward in the direction of movement, leaving behind a layer of powder having the desired thickness.

In still another embodiment, a downdraft mechanism for controlling temperature of the powder is provided which includes a support defining the target area, a mechanism for directing air to the target area, and a mechanism for controlling the temperature of the air prior to reaching the target area. The support preferably includes porous medium on which the powder is deposited and a plenum adjacent the porous medium. Thus, the controlled temperature air is directed to the powder in the target area and helps control the temperature of the sintered and unsintered powder in the target area.

As can be appreciated from the above general description, the method and apparatus of the present invention solves many of the problems associated with known part production methods. First, the present invention is well suited for prototype part production or replacement part production of limited quantities. Further, the method and apparatus hereof are capable of making parts of complex configurations unobtainable by conventional production methods. Further, the present invention eliminates tool wear and machine design as limiting factors on the tolerances obtainable in producing the part. Finally, with the apparatus of the present invention incorporated into a CAD/CAM environment, a large number of replacement parts can be programmed into the computer and can be easily produced with little set-up or human intervention.

FIGURE 1 is a schematic representation of the apparatus of the present invention;

FIGURE 2 is a schematic showing a portion of the layered build up of a part produced in accordance with the present invention, and illustrating the raster scan pattern of the laser beam in the target area;

FIGURE 3 is a block diagram depicting the interface hardware between the computer, laser and galvonometers of the present invention;

FIGURE 4 is a persp ctiv view of an example part produc d in accordance with the present invention;

FIGURE 5 is a s ctional vi w with parts broken away and in phantom, of the part illustrated in FIGURE 4;

FIGURE 6 is a flow chart of th data metering program in accordance with the present invention;

FIGURE 7 is a sectional view taken along line 7-7 of FIGURE 4;

FIGURE 8 illustrates in diagram form the correlation between a single sweep of the laser across the layer of FIGURE 7 and the control signals of the present invention;

FIGURE 9 is a schematic, vertical, sectional view of the powder dispensing device of the present invention distributing powder in a layer on the part being produced;

FIGURE 10 is a schematic, perspective view of the powder dispensing device of the present invention; and

FIGURE 11 is a schematic view of an apparatus for moderating the temperature of the powder in accordance with the present invention.

Turning now to the drawings, FIGURE 1 broadly illustrates the apparatus 10 in accordance with the present invention. Broadly speaking, the apparatus, 10 includes a laser 12, powder dispenser 14, and laser control means 16. In more detail, the powder dispenser 14 includes a hopper 20 for receiving the powder 22 and having an outlet 24. The outlet 24 is oriented for dispensing the powder to a target area 26, which in FIGURE 1 is generally defined by the confinement structure 28. Of course, many alternatives exist for dispensing the powder 22.

The components of the laser 12 are shown somewhat schematically in FIGURE 1 and include a laser head 30, a safety shutter 32, and a front mirror assembly 34. The type of laser used is dependent upon many factors, and in particular upon the type of powder 22 that is to be sintered. In the embodiment of FIGURE 1, a Nd:YAG laser (Lasermetrics 9500Q) was used which can operate in a continuous or pulsed mode with a hundred-watt maximum outlet power in the continuous mode. The laser beam output of the laser 12 has a wavelength of approximately 1060 nM, which is near infrared. The laser 12 illustrated in FIGURE 1 includes an internal pulse rate generator with a selectable range of about one kiloHertz to forty kiloHertz, and an approximately six nanosecond pulse duration. In either the pulsed or continuous mode, the laser 12 can be modulated on or off to selectively produce a laser beam which travels generally along the path shown by the arrows in FIGURE 1.

To focus th las r beam, a diverging lens 36 and converging lens 38 are disposed along the path of travel of the laser beam as shown in

FIGURE 1. Using just the converging lens 38, the location of th true focal point is not easily controlled by varying th distance between th converging lens 38 and the laser 12. The diverging lens 36 placed between the laser 12 and convening lens 38 creates a virtual focal point between the diverging lens 36 and the laser 12. Varying the distance between the converging lens 38 and the virtual vocal point, allows control of the true focal point along the laser beam path of travel on the side of the converging lens 38 remote from the laser 12. In recent years there have been many advances in the field of optics, and it is recognized that many alternatives are available to efficiently focus the laser beam at a known location.

In more detail, the laser control means 16 includes computer 40 and scanning system 42. In a preferred embodiment, the computer 40 includes a microprocessor for controlling the laser 12 and a CAD/CAM system for generating the data. In the embodiment illustrated in FIGURE 1, a personal computer is used (Commodore 64) whose primary attributes include an accessible interface port and a flag line which generates a nonmaskable interrupt.

As shown in FIGURE 1, the scanning system 42 includes a prism 44 for redirecting the path of travel of the laser beam. Of course, physical layout of the apparatus 10 is the primary consideration in determining whether a prism 44, or a plurality of prisms 44, are needed to manipulate the path of travel of the laser beam. The scanning system 42 also includes a pair of mirrors 46, 47 driven by respective galvonometers 48, 49. The galvonometers 48, 49 coupled to their respective mirrors 46, 47 to selectively orientate the mirrors 46, 47. The galvonometers 46, 47 are mounted perpendicular to each other such that the mirrors 46, 47 are mounted nominally at a right angle to each other. A function generator driver 50 controls the movement of the galvonometer 48 (galvonometer 49 is slaved to the movement of galvonometer 48) so that the aim of the laser beam (represented by the arrows in FIGURE 1) can be controlled in the target area 26. The driver 50 is operatively coupled to the computer 40 as shown in FIGURE 1. It will be appreciated that alternative scanning methods are available for use as the scanning system 42, including acusto-optic scanners, rotating polygon mirrors, and resonant mirror scanners.

Turning to FIGURE 2 of the drawing, a portion of a part 52 is schematically illustrated and shows four layers 54-57. The aim of the laser beam, labeled 64 in FIGURE 2, is directed in a raster scan pattern as at 66. As used herein, "aim" is used as a neutral term indicating direction, but does not imply th modulation state of the laser 12. For conv nience, the axis 68 is consider d the fast scan axis, while the axis 70 is referred to as the slow scan axis. Axis 72 is th direction of part build-up.

Turning to FIGURES 9 and 10, an alternative form of powd r disp nser 20 is illustrated. Broadly speaking, a support defines a target area 102 where the aim of the beam 64 is directed (see FIG. 1). A hopper 104 dispenses the powder 106 through opening 108 into the target area 102. A metering roller (not shown) is disposed in the opening 108, such that when rotated the metering roller deposits a metered mound of powder in a line at end 110 of the target area 102.

A leveling mechanism 114 spreads the mound of powder 106 from end 110 to the other end 112 of the target area. The leveling mechanism 114 includes a cylindrical drum 116 having an outer knurled surface. A motor 118 mounted on bar 120 is coupled to the drum 116 via pulley 122 and belt 124 to rotate the drum.

The leveling mechanism 114 also includes a mechanism 126 for moving the drum 116 between end 110 and end 112 of the target area. The mechanism 126 comprises an X/Y table for moving the bar 120 horizontally and vertically. That is, table 128 is fixed while plate 130 is selectively movable relative to table 128.

Still another embodiment is shown in FIGURE 11 for controlling the temperature of the article being produced. Undesirable shrinkage of the article being produced has been observed to occur due to differences between the temperature of the particles not yet scanned by the directed energy beam and the temperature of the previously scanned layer. It has been found that a downward flow of controlled-temperature air through the target area is able to moderate such undesirable temperature differences. The controlled-temperature air downdraft system 132 of FIGURE 11 reduces thermal shrinkage by providing heat transfer between the controlled-temperature air and the top layer of powder particles to be sintered. This heat transfer moderates the temperature of a the top layer of particles to be sintered, controls the mean temperature of the top layer, and removes bulk heat from the article being produced, thereby reducing its bulk temperature and preventing the article from growing into the unsintered material. The temperature of the incoming air is adjusted to be above the softening point of the powder, but below the temperature at which significant sintering will occur.

The downdraft system 132 broadly includes a support 134 defining target area 136, means for directing air to the target area, and a mechanism for controlling the temperature of the incoming air, such as resistance heater 142. The air directing means includes chamber 138 surrounding support 134, fan 140 and/or vacuum 141. A window 144 admits the aim of the beam 64 (FIG. 1) to the

target area 136. A powd r dispensing mechanism (not shown), such as illustrated in FIGURES 1 or 10 is disposed at least partially in the chamber 138 to dispense powder onto target area 136.

Support 134 preferably comprises a filter medium 146 (such as a small-pore paper) on top of a honey-comb porous medium 148. A plenum 150 is disposed for gathering air for passage to outlet 152. Of course, the outlet 152 is connected to vacuum 141 or other air handling mechanism.

Operation

A fundamental concept of the present invention is the build up of a part in a layer-by-layer manner. That is, a part is considered a plurality of discrete cross-sectional regions which cumulatively comprise the three-dimensional configuration of the part. Each discrete cross-sectional region has defined two-dimensional boundaries - of course, each region may have unique boundaries. Preferably, the thickness (dimension in the axis 72 direction) of each layer is constant.

In the method, a first portion of powder 22 is deposited in the target area 26 and selectively sintered by the laser beam 64 to produce a first sintered layer 54 (FIGURE 2). The first sintered layer 54 corresponds to a first cross-sectional region of the desired part. The laser beam selectively sinters only the deposited powder 22 within the confines of the defined boundaries.

There are, of course, alternative methods of selectively sintering the powder 22. One method is for the aim of the beam to be directed in a "vector" fashion - that is, the beam would actually trace the outline and interior of each cross-sectional region of the desired part. Alternatively, the aim of the beam 64 is scanned in a repetitive pattern and the laser 12 modulated. In FIGURE 2, a raster scan pattern 66 is used and is advantageous over the vector mode primarily in its simplicity of implementation. Another possibility is to combine the vector and raster scan methods so that the desired boundaries of the layer are traced in a vector mode and the interior irradiated in a raster scan mode. There are, of course, trade-offs associated with the method chosen. For example, the raster mode has a disadvantage when compared to the vector mode in that arcs and lines which are not parallel to the axes 68, 70 of the raster pattern 66 of the laser beam 64 are only approximated. Thus, in some cases resolution of the part can be degraded when produced in the raster pattern mode. However, the raster mode is advantageous over the vector mode in the simplicity of implementation.

Turning to FIGURE 1, th aim of the laser beam 64 is scanned in the target area 26 in a continuous rast r pattern. Broadly speaking, the driver 50 controls galvonom ters 48, 49 to made the raster pattern 66 (se FIGURE 2). Shifting mov m nt of the mirror 46 controls movement of the aim of the laser beam 64 in the fast scan axis 68 (FIGURE 2), while movement of the mirror 47 controls movement of the aim of the laser beam 64 in the slow scan access 70.

The present position of the aim of the beam 64 is fed back through the driver 50 to the computer 40 (see FIGURE 3). As described below, in more detail, the computer 40 possesses information relating to the desired cross-sectional region of the part then being produced. That is, a portion of loose powder 22 is dispensed into the target area 26 and the aim of the laser beam 64 moved in its continuous raster pattern. The computer 40 modulates the laser 12 to selectively produce a laser beam at desired intervals in the raster pattern 66. In this fashion, the directed beam of the laser 12 selectively sinters the powder 22 in the target area 26 to produce the desired sintered layer with the defined boundaries of the desired cross-sectional region. This process is repeated layer-by-layer with the individual layers sintered together to produce a cohesive part - e.g. part 52 of FIGURE 2.

Because of the relatively low output power of the laser head 30 illustrated in FIGURE 1, the powder 22 consisted of a plastic material (e.g. ABS), based on the lower heat of fusion of most plastics, which is compatible with the lower power laser. Several post formation treatments are contemplated for the parts produced by the apparatus 10 of the present invention. For example, if such a produced part is to be used only as a prototype model or as a die for sandcast or lost wax casting, then post-formation treatment may not be necessary. In some situations, certain surfaces of the parts produced may be designed for close tolerances, in which case some post-fabrication machining would be accomplished. Alternatively, some types of parts may require certain material properties which can be achieved by heat-treating and/or chemically treating the part. For example, the granule size of the powder 22 could be such to produce a part having an open porosity and epoxy or similar substance injected into the part could achieve the desired material properties - e.g. compression strength, abrasion resistance, homogeneity, etc.

Several characteristics of powder 22 have been identified which improve performance. First, energy absorption by the powder can be controlled by the addition of a dye such as carbon black. Adjusting the concentration and composition of the additive controls the absorbtivity constant K of the powder. Generally, energy absorptivity is governed by the exponential decay relation:

$$I(z) = I_o \exp(K Z)$$

wher I(z) is th optical intensity (powd r per unit area) in th powder at a distance z normal to the surfac , I_o is the surface value of I (intensity at the surface), and K is the absorptivity constant. Adjustment of the absorptivity constant K and adjustment of the layer thickness in which a given fraction of beam energy is absorbed gives overall control of the energy absorbed in the process.

Another important characteristics of the powder is the aspect ratio of the particles (i.e. ratio of the particle's maximum dimension to its minimum dimension). That is, particles with certain aspect ratios tend to warp during shrinkage of the part. With particles having low aspect ratios, i.e. nearly spherical, part shrinkage is more three dimensional, resulting in greater warp. When particles with high aspect ratios are used (e.g. flakes or rods) shrinkage primarily is in a vertical direction reducing or eliminating warping of the part. It is believed that high aspect ratio particles have greater freedom to accommodate bonding and interparticle contact is preferentially oriented in horizontal planes causing shrinkage to occur primarily in a vertical direction.

Turning now to FIGURES 9 and 10, the dispensing mechanism 114 has been found to provide a controlled level layer of powder in the target area 102 without disturbing the part being produced. A metered amount of powder 106 is deposited at end 110 of the target area 102. The drum 116 is spaced away from end 110 when the powder 106 is dispensed. In the system illustrated in FIGURE 10, the plate 130 and bar 120 (and attached mechanisms) are raised vertically after the powder is dispensed in the mound. Travel of the plate 130 towards the hopper 104 brings the drum 116 into position adjacent the mound of powder lined up along end 110. The drum 116 is lowered to contact the mound of powder and brought horizontally across the target area 102 to spread the mound of powder in a smooth even layer. Of course, the precise location of plate 130 relative to table 128 can be controlled, so that the spacing between drum 116 and target area 102 can be precisely controlled to yield the desired thickness to the layer of powder. Preferably, the spacing between the drum 116 and target area 102 is constant to give a parallel motion, but othe spacing options are available.

As the drum 116 is moved horizontally across the target area 102 from end 110 to end 112, motor 118 is activated to counter-rotate the drum 116. As shown in FIGURE 9, "counter-rotation" means the drum 116 is rotated in the direction R counter to the direction of movement M of the drum 116 horizontally across the target ar a 102.

In more detail (FIG. 9), the drum 116 is counter-rotated at high speed to contact the mound of powder 106 along the trailing edg 160. The mechanical action of th drum on the powder ej cts th powder to the direction of movement M so that the ejected particles fall in th region of the leading edge of the powder 162. As illustrated in FIGURE 9, a smooth, level layer of powder is left behind the drum 116 (between drum 116 and end 110) as depicted at 164.

FIGURE 9 also illustrates schematically that the powder 106 can be distributed over the target area without disturbing previously sintered powder 166 or unsintered powder 168. That is, the drum 116 is moved across the target area 102 without transmitting shear stress to the previously built up layers and without disturbing the article as it is being produced. The absence of such sheer stress permits a smooth layer of powder 106 to be distributed on the fragile substrate in the target area, which includes both the sintered particles 166 and the unsintered particles 168.

Interface and Software

The interface hardware operatively interconnects the computer 40 with the laser 12 and galvonometers 47, 48. The output port of the computer 40 (see FIGURES 1 and 3) is directly connected to the laser 12 to selectively modulate the laser 12. When operated in the pulsed mode, the laser 12 is easily controlled by digital inputs to the pulsed gate input of the laser. Galvonometer 48 is driven by the function generator driver 50 to drive the beam in the fast scan axis 68 independent of any control signals from the computer 40. However, a position feedback signal from the galvonometer 48 is fed to a voltage comparator 74 as shown in FIGURE 3. The other input to the comparator is connected to the digital-to-analog convertor 76 which is indicative of the least significant six bits (bits 0-5) of the user port of the computer 40. As shown in FIGURE 3, the output of the voltage comparator 74 is connected to the flag line on the user port of the computer 40. When the voltage comparator determines that the feedback signal from the galvonometer 48 crosses the signal from the digital-to-analog convertor 76, the flag line goes low causing a nonmaskable interrupt. As discussed below, the nonmaskable interrupt causes the next byte of data to put out on the user port of a computer 40.

Finally, as shown in FIGURE 3, the galvonometer 49 driving the aim of the laser beam 64 in the slow scan axis 70, is controlled by a second digital to analog convertor 78. The digital-to-analog convertor 78 is driven by a counter 79 which increments with each sweep of the aim of the beam 64 in the fast scan axis 68. The eight byte count r is designed to overflow after 256 scans in the fast

scan axis 68 to start a new cycle or raster scan patt rn 66.

Preferably, the control information (i.e. d fined boundari s of the cross-sectional regions) data for each raster pattern 66 would be determined by a CAD system given the overall dimensions and configuration of the part to be produced. Whether programmed or derived, the control information data for each raster pattern 66 is stored in the computer memory as a series of eight bit words. The data format represents a pattern of "on" and "off" regions of the laser 12, versus distance along the raster pattern 66 traveled by the aim of the beam 64. The data is stored in a "toggle-point" format where the data represents the distance along each raster scan pattern 66 where the laser is modulated (i.e. turned from on to off or from off to on). Although a "bit map" format might be used, the toggle point format has been found more efficient for the production of high resolution parts.

For each eight bit word, the least significant six bits (bits 0-5) represent the location of the next toggle point - i.e. the next location for modulation of the laser 12. The next bit (bit 6) represents whether the laser is on or off immediately before the toggle point identified in the least significant six bits. The most significant bit (MSB or bit 7) is used for looping and for controlling the slow scan axis 70 of the aim of the beam 64. Because the Commodore 64 had limited memory, looping was required - it being understood that a computer 40 with more memory would not require looping.

FIGURE 6 represents the flow chart for the data metering program. The data metering program is run whenever the flagline goes low causing a non-maskable interrupt (see FIGURE 3). The interrupt causes the microprocessor of the computer 40 to retrieve a two byte interrupt vector which points to the location in memory where program control is transferred at interrupt. As shown in FIGURE 6, the data metering program first pushes the registers onto the stack and then loads the next byte of data into the accumulator. The data word is also output to the user port with the sixth bit used to modulate the laser 12 (FIGURE 3).

As shown in FIGURE 6, the most significant bit (MSB or bit 7) of the data word in the accumulator is examined. If the value of the most significant bit is one, that means the end of the loop has not been reached; therefore the data pointer is incremented, registers are restored from the stack, and the data metering program is exited, returning control to the microprocessor at the location of interrupt. If the most significant bit in the accumulator is zero, the data word is the last word in the loop. If the data word is the last word in the loop, the next bit in memory is a loop counter and the following two bytes are a vector pointing to the top of the loop. As can be seen from FIGURE 6, if the most significant bit equals zero (nd of the loop) the loop counter (next bit) is decremented and analyzed. If the loop count r is still gr ater than zero, the data pointer assumes the value from the next two memory bytes after the loop counter, registers are pulled from the stack and program control returns to the location of interrupt. On the other hand, if loop counter is zero, the data pointer is incremented by three and the loop counter is reset to ten before exiting the program. It can be appreciated that the need for such looping is absolved if the memory size of the computer 40 is adequate.

Example

In FIGURES 4 and 5, an example part 52 is illustrated. As can be seen from the drawing, the example part 52 assumes an unusual shape in that it is not symmetrical and would be difficult to fabricate using conventional machining methods. For reference purposes, the part 52 includes an outer base structure 80 having an interior cavity 82 and a pillar 84 disposed within the cavity 82 (see FIGURE 4). FIGURE 5 shows the part 52 within the confinement structure 28 defining the target area 26 illustrated in FIGURE 1. As shown in FIGURE 5, some of the powder 22 is loose, while the remainder of the powder is selectively sintered to comprise the structure of the part 52. FIGURE 5 is shown in vertical section with parts broken away and outlined in phantom to show the sintered cohesive portions of the part 52.

FIGURE 7 shows a horizontal cross-sectional region, taken along line 7-7 of FIGURE 4. FIGURE 7 represents a discrete layer 86 associated with the cross-sectional region of the part being produced. As such, the sintered layer 86 of FIGURE 7 is a product of a single raster pattern 66 as illustrated in FIGURE 2.

For reference purposes, a sweep line through the sintered layer 86 has been labeled "L." FIGURE 8 illustrates the software and hardware interface operation during the sweep L. The top graph shows the position of feedback signal from the fast axis galvo 48 and the output signal of the first digital to analog convertor 76 (compare FIGURE 3). The voltage comparator 74 generates an output signal to the flag line of the computer 40 every time the feedback signal and first D/A output signal cross.

In the top graph of FIGURE 8, these points are labeled T to represent toggle points. As can be seen from the bottom graph of FIGURE 8, the flag line generates a nonmaskable interrupt corresponding to each toggle point T. Th sixth bit of each data word is analyzed and the current stat of the laser 12 will reflect the value. The penultimate

graph of FIGURE 8 shows the laser modulation signal f r the sweep line L of FIGURE 7. The second graph of FIGURE 8 shows that a high-going edge in th most significant bit will be encount red at the end of each sweep of the aim of the laser beam 64 in the fast scan axis 68. As shown in FIGURES 3 and 6, the counter 79 increments on a high going edge, and outputs a signal to the second digital-analog convertor 78 to drive the slow axis galvonometer 49.

As can be seen from the example illustrated in the drawing; parts of complex shape can be produced with relative ease. Those skilled in the art will appreciate that the part 52 illustrated in FIGURE 4 would be difficult to produce using conventional machining methods. In particular, machine tool access would make the fabrication of cavity 82 and pillar 84 difficult, if not impossible, to produce if the part 52 were of a relatively small size.

In addition to avoiding the access problem, it will be appreciated that the production accuracy is not dependent upon machine tool wear and the accuracy of mechanical components found in conventional machine tools. That is, the accuracy and tolerances of the parts produced by the method and apparatus of the present invention are primarily a function of the quality of the electronics, the optics, and the implementing software. Of course, heat transfer and material considerations do affect the tolerances obtainable.

Those skilled in the art will appreciate that conventional machining techniques require considerable human intervention and judgment. For example, a conventional machining process, such as milling, would require creativity to make such decisions as tool selection, part segmenting, sequence of cuts, etc. Such decisions would even be more important when producing a control tape for a tape control milling machine. On the other hand, the apparatus of the present invention only requires the data relating to each cross-sectional region of the part being produced. While such data can be simply programmed into the computer 40, preferably, the computer 40 includes a CAD/CAM system. That is, the CAD/CAM portion of the computer 40 is given the overall dimensions and configurations of the desired part to be produced and the computer 40 determines the boundaries for each discrete cross-sectional region of the part. Thus, a vast inventory of part information can be stored and fed to the computer 40 on a selectable basis. The apparatus 10 produces a selected part without set-up time, part specific tooling, or human intervention. Even the complex and xpensiv di s associated with powd r m tallargy and conventional casting techniques are avoided.

While larg quantity production runs and certain part material characteristics might b most advantageously made using conventional fabrication techniques, the m thod and apparatus 10 of the present invention is useful in many contexts. In particular, prototype models and casting patterns are easily and inexpensively produced. For example, casting patterns are easily made for use in sand casting, lost wax casting, or other forming techniques. Further, where desired quantities are very small, such as with obsolete replacement parts, production of such replacement parts using the apparatus 10 of the present invention has many advantages. Finally, the use of the apparatus 10 may be useful where size of production facilities is a major constraint, such as on-ship or in outerspace.

Claims

1. A method of producing a part (52) comprising the steps of depositing a first layer of sinterable powder (22) onto a target surface (26); scanning the aim of a directed energy beam (64) over the target surface (26) to fuse selected portions of the first layer (54) of the powder corresponding to a first cross-sectional region of the part (52) by operating the beam (64) when the aim of the beam (64) is within boundaries defined by said first cross-sectional region;

   depositing a second layer of sinterable powder (22) onto the first layer (54);

   scanning the aim of a directed energy beam (64) over the target surface (26) to sinter selected portions of the second layer (55) corresponding to a second cross-sectional region of the part (52) by operating the beam (64) when the aim of the beam is within boundaries defined by said cross-sectional region, so that sintered portions of the first and second layers (54, 55) are joined during the sintering of said second layer (55); and

   depositing further successive layers of sinterable powder (22) onto the previous layers and sintering a layer of each successive portion to produce a part (52) comprising a plurality of sintered layers (54, 55, 56, 57);

   characterised by:

   controlling the temperature of sintered and unsintered powder at the target surface (26).

2. A method according to claim 1, characterised by the scanning steps directing the aim of the beam (64) only within the respective boundaries of the r spectiv cross-sectional r gions.

3. A method according to claim 1, characteris d by the scanning and sintering steps further including the st ps of moving th aim of th

beam (64) in a rast r scan (66) and turning on and off th beam (64) during the raster scan (66) wh n the aim is within the boundari s.

4. A method according to claim 3, characterised by producing the raster scan (66) by redirecting the beam (64) in a first direction (68) and redirecting the beam (64) from the first direction to a second direction (70) to impact a generally planar target area.

5. A method according to claim 3, characterised by the step of redirecting of the beam (64) including using a pair of mirrors (46, 47) coupled to respective galvanometers (48, 49), the first mirror (46) being shifted to produce movement of the beam (64) in the target surface (26) in a first general direction (68), and the second mirror (47) being shifted to produce a movement of the beam (64) in the target surface (26) in a second general direction (70) perpendicular to the first direction (68).

6. A method according to claim 1, characterised by impregnating the part (52) with an adhesive.

7. A method according to claim 1, characterised by the powder (22) being continuously deposited onto the target surface (26).

8. A method according to claim 1, characterised by the depositing step including the substeps of dispensing a mound of powder (106) proximate one end (110) of the target surface (102); and

moving a counter-rotating drum (116) from said one end (110) to another end (112) of the target surface (102) to contact the mound of powder and leave a layer (164) of powder behind the moving drum (116).

9. An apparatus for performing a method according to claim 1 comprising:

an energy source (12) operable to emit a focused energy beam (64);

a structure (28) having a target surface (26) at which a part (52) is to be produced in layerwise fashion;

means for dispensing a layer of sinterable powder (22) into said target area (26); and

a controller (16) operable to direct the aim of the focused energy beam (64) to selectively sinter within defined boundaries a portion of each layer (54, 55, 56, 57) of powder (22) dispensed in said target surface (26),

the controller (16) including a scanning system (42) to move the aim of the energy beam (64) in said target area (26) in a repetitive patt rn (66), and a comput r (40) programmed with th d fin d boundari s of each layer (54, 55, 56, 57) of th part (52) to turn on the energy beam (64) with the aim of the beam (64) within the defined boundaries for each layer (54, 55, 56, 57) as the aim of the beam (64) is moved in the target area (26), being operable to direct the energy beam (64) over the target surface (26) to sinter selected portions of sequential layers (54, 55, 56, 57) of powder (22) within respective defined boundaries corresponding to sequential cross-sectional regions of a part; and

the dispensing means (14) being operable to dispense successive layers of powder (55, 56, 57), each after the selective sintering of a prior layer (54, 55, 56), so that sintered selected portions of one of the successive layers are joined to sintered portions of a prior layer, to produce a part (52) comprising a plurality of layers (54, 55, 56, 57) sintered together; the apparatus being characterised by means (132) for controlling the temperature of sintered and unsintered powder at the target surface (26).

10. An apparatus according to claim 9, characterised by the energy source comprising a laser so that the energy beam (64) is a laser beam and by the controller (16) including means (42, 44, 35, 38) for directing the aim of the laser beam (64) in said target surface (26) and means for modulating the laser by turning the beam (64) on and off to selectively sinter the powder (22) in the target surface (26).

11. An apparatus according to claim 10, characterised by the directing means (42) being operable to move the aim of the laser beam (64) in a raster scan (66) of the target surface (26).

12. An apparatus according to claim 10, characterised by the directing means including one or more lenses (36, 38) to focus the laser beam (64).

13. An apparatus according to claim 10, characterised by the directing means including a prism (44) to change the direction of the laser beam (64) emitted from the laser means (12).

14. An apparatus according to claim 9, characterised by means (132) for directing controlled temperature air to the part (52) to moderate the temp rature of the part (52).

15. An apparatus according to claim 9, characterised by th computer (40) b ing operable to determin th defined boundari s of the selected portions of ach layer (54, 55, 56, 57) of the part (52) given the overall dimensions of the part (52).

16. An apparatus according to claim 9, characterised by the powder dispensing means including a hopper (104) for receiving a powder (106), a metered outlet (108), directing the powder (106) to the target surface (102), and a counter-rotating drum (116) moved across the target surface (102) to distribute the powder (106) in the target surface (102).

17. An apparatus according to claim 9, characterised by said dispensing means (14) being operable to dispense plastic, ceramic, polymer, or metal powder.

18. Use of an apparatus for performing a method according to claim 1, the apparatus comprising:

an energy source (12) operable to emit a focused energy beam (64);

a structure (28) having a target surface (26) at which a part (52) is to be produced in a layerwise fashion;

means (14) for dispensing a layer of a sinterable powder (22) into said target area (26); and

a controller (16) operable to direct the aim of the focused energy beam (64) to selectively sinter within defined boundaries a portion of each layer (54, 55, 56, 57) of powder (22) dispensed in said target surface (26),

the controller (16) being operable to direct the energy beam (64) over the target surface (26) to sinter selected portions of sequential layers (54, 55, 56, 57) of powder (22) within respective defined boundaries corresponding to sequential cross-sectional regions of a part;

the dispensing means (14) being operable to dispense successive layers of powder (55, 56, 57), each after the selective sintering of a prior layer (54, 55, 56), so that sintered selected portions of one of the successive layers are joined to sintered portions of a prior layer, to produce a part (52) comprising a plurality of layers (54, 55, 56, 57) sintered together; and characterised by means (132) for controlling the temperature of sintered and unsintered powder at the target surface (26).

Patentansprüche

1. Verfahr n zur Herst llung eines T iles (52), das di folgenden Verfahr nsschritte aufweist:
Aufbringen einer ersten Schicht eines sinterfähigen Pulvers (22) auf eine Aufnahmefläche (26);
Abtasten des Zieles eines gerichteten Energiestrahles (64) über der Aufnahmefläche, um die ausgewählten Abschnitte der ersten Schicht (54) des Pulvers entsprechend einem ersten Querschnittsbereich des Teiles (52) zu schmelzen, indem der Strahl (64) eingesetzt wird, wenn das Ziel des Strahles (64) innerhalb der Grenzen zu finden ist, die durch den ersten Querschnittsbereich abgegrenzt werden;
Aufbringen einer zweiten Schicht des sinterfähigen Pulvers (22) auf die erste Schicht (54);
Abtasten des Zieles eines gerichteten Energiestrahles (64) über der Aufnahmefläche (26), um die ausgewählten Abschnitte der zweiten Schicht (55) entsprechend einem zweiten Querschnittsbereich des Teiles (52) zu sintern, indem der Strahl (64) eingesetzt wird, wenn das Ziel des Strahles innerhalb der Grenzen zu finden ist, die durch den Querschnittsbereich abgegrenzt werden, so daß die gesinterten Abschnitte der ersten und der zweiten Schicht (54, 55) während des Sinterns der zweiten Schicht (55) verbunden werden; und
Aufbringen weiterer nachfolgender Schichten des sinterfähigen Pulvers (22) auf die vorangegangenen Schichten und Sintern einer Schicht eines jeden nachfolgenden Abschnittes, um ein Teil (52) herzustellen, das eine Vielzahl von gesinterten Schichten (54, 55, 56, 57) aufweist;
dadurch gekennzeichnet, daß die Temperatur des gesinterten und des nicht gesinterten Pulvers auf der Aufnahmefläche (26) gesteuert wird.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die Abtastschritte das Ziel des Strahles (64) nur innerhalb der entsprechenden Grenzen der entsprechenden Querschnittsbereiche führen.

3. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die Schritte des Abtastens und des Sinterns außerdem die Schritte des Bewegens des Zieles des Strahles (64) in eine Rasterabtastung (66) und des Ein- und Ausschaltens des Strahles (64) während der Rasterabtastung (66) umfassen, wenn das Ziel sich innerhalb der Grenzen befindet.

4. Verfahren nach Anspruch 3, dadurch gekennzeichnet, daß die Rasterabtastung (66) erhalten

wird, indem der Strahl (64) in einer ersten Richtung (68) zurückgeführt wird, und indem d r Strahl (64) aus der ersten Richtung in eine zw it Richtung (70) zurückgeführt wird, um auf eine im allgemeinen ebene Aufnahmefläche aufzutreffen.

5. Verfahren nach Anspruch 3, dadurch gekennzeichnet, daß der Schritt der Rückführung des Strahles (64) die Verwendung eines Spiegelpaares (46, 47), das mit den entsprechenden Galvanometern (48, 49) verbunden ist, umfaßt, wobei der erste Spiegel (46) verschoben wird, um die Bewegung des Strahles (64) in der Aufnahmefläche (26) in einer ersten Hauptrichtung (68) zu bewirken, und wobei der zweite Spiegel (47) verschoben wird, um die Bewegung des Strahles (64) in der Aufnahmefläche (26) in einer zweiten Hauptrichtung (70) senkrecht zur ersten Richtung (68) zu bewirken.

6. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß das Teil (52) mit einem Klebstoff imprägniert wird.

7. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß das Pulver (22) kontinuierlich auf der Aufnahmefläche (26) aufgebracht wird.

8. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß der Schritt des Aufbringens die folgenden Teilschritte umfaßt:
dosiertes Aufbringen einer Aufschüttung des Pulvers (106) in der Nähe eines Endes (110) der Aufnahmefläche (102); und
Bewegen einer gegenläufigen Walze (116) von einem Ende (110) zum anderen Ende (112) der Aufnahmefläche (102), um mit der Aufschüttung des Pulvers in Berührung zu kommen und hinter der sich bewegenden Walze (116) eine Schicht (164) des Pulvers zurückzulassen.

9. Vorrichtung für die Durchführung des Verfahrens nach Anspruch 1, die aufweist:
eine Energiequelle (12), die so funktionsfähig ist, daß sie einen gebündelten Energiestrahl (64) emittiert;
eine Konstruktion (28), die eine Aufnahmefläche (26) besitzt, auf der ein Teil (52) schichtartig hergestellt werden soll;
eine Einrichtung für das dosierte Aufbringen einer Schicht des sinterfähigen Pulvers (22) auf die Aufnahmefläche (26); und
einen Regler (16), der so funktionsfähig ist, daß er das Ziel des g bünd lt n En rgiestrahles (64) führt, um s lektiv innerhalb festg legter Grenzen inen Abschnitt einer jeden Schicht (54, 55, 56, 57) des Pulv rs (22), das auf die Aufnahmefläche (26) dosiert aufgebracht wurde, zu sintern,
w bei der Regl r (16) ein Abtastanlage (42), um das Ziel des Energiestrahles (64) in die Aufnahmefläche (26) in einem sich wiederholenden Muster (66) zu bewegen, und einen Computer (40) umfaßt, der mit den festgelegten Grenzen einer jeden Schicht (54, 55, 56, 57) des Teiles (52) programmiert ist, um den Energiestrahl (64) einzuschalten, wobei sich das Ziel des Strahles (64) innerhalb der festgelegten Grenzen für jede Schicht (54, 55, 56, 57) befindet, während das Ziel des Strahles (64) in die Aufnahmefläche (26) bewegt wird, und wobei er funktionsfähig ist, um den Energiestrahl (64) über die Aufnahmefläche (26) zu führen, um ausgewählte Abschnitte der aufeinanderfolgenden Schichten (54, 55, 56, 57) des Pulvers (22) innerhalb der entsprechenden festgelegten Grenzen in Übereinstimmung mit den aufeinanderfolgenden Querschnittsbereichen eines Teiles zu sintern; und
wobei die Einrichtung für das dosierte Aufbringen (14) so funktionsfähig ist, daß die nachfolgenden Schichten des Pulvers (55, 56, 57) jeweils nach dem selektiven Sintern einer vorangegangenen Schicht (54, 55, 56) dosiert aufgebracht werden, so daß die gesinterten ausgewählten Abschnitte einer jeden der nachfolgenden Schichten mit den gesinterten Abschnitten einer vorangegangenen Schicht verbunden werden, um ein Teil (52) herzustellen, das eine Vielzahl von Schichten (54, 55, 56, 57) aufweist, die miteinander gesintert wurden;
wobei die Vorrichtung dadurch gekennzeichnet wird, daß eine Einrichtung (132) für die Steuerung der Temperatur des gesinterten und des nicht gesinterten Pulvers auf der Aufnahmefläche (26) vorhanden ist.

10. Vorrichtung nach Anspruch 9, dadurch gekennzeichnet, daß die Energiequelle einen Laser aufweist, so daß der Energiestrahl (64) ein Laserstrahl ist, und dadurch, daß der Regler (16) eine Einrichtung (42, 44, 35, 38) für das Führen des Zieles des Laserstrahles (64) in die Aufnahmefläche (26) und eine Einrichtung für das Steuern des Lasers umfaßt, indem der Strahl (64) ein- und ausgeschaltet wird, um das Pulver (22) in der Aufnahmefläche (26) selektiv zu sintern.

11. Vorrichtung nach Anspruch 10, dadurch gekennzeichn t, daß die Führungs inrichtung (42) so funktionsfähig ist, daß das Zi l des Laserstrahles (64) in eine Rasterabtastung (66) der Aufnahmefläche (26) bew gt wird.

12. Vorrichtung nach Anspruch 10, dadurch gek nnzeichn t, daß di Führungseinrichtung eine oder mehrere Linsen (36, 38) umfaßt, um den Laserstrahl (64) zu bündeln.

13. Vorrichtung nach Anspruch 10, dadurch gekennzeichnet, daß die Führungseinrichtung ein Prisma (44) umfaßt, um die Richtung des Laserstrahles (64) zu verändern, der aus der Lasereinrichtung (12) emittiert wird.

14. Vorrichtung nach Anspruch 9, dadurch gekennzeichnet, daß eine Einrichtung (132) für das Zuführen von Luft mit geregelter Temperatur zum Teil (52) vorhanden ist, um die Temperatur des Teiles (52) zu mäßigen.

15. Vorrichtung nach Anspruch 9, dadurch gekennzeichnet, daß der Computer (40) so funktionsfähig ist, daß die festgelegten Grenzen der ausgewählten Abschnitte einer jeden Schicht (54, 55, 56, 57) des Teiles (52) bestimmt werden, wodurch die Gesamtabmessungen des Teiles (52) erhalten werden.

16. Vorrichtung nach Anspruch 9, dadurch gekennzeichnet, daß die Einrichtung für das dosierte Aufbringen des Pulvers einen Trichter (104) für das Aufnehmen des Pulvers (106), eine Dosieraustrittsöffnung (108), die das Pulver (106) zur Aufnahmefläche (102) führt, und eine gegenläufige Walze (116) umfaßt, die sich über die Aufnahmefläche (102) bewegt, um das Pulver (106) auf der Aufnahmefläche (102) zu verteilen.

17. Vorrichtung nach Anspruch 9, dadurch gekennzeichnet, daß die Einrichtung für das dosierte Aufbringen (14) so funktionsfähig ist, daß ein Kunststoff-, Keramik-, Polymer- oder Metallpulver dosiert aufgebracht werden kann.

18. Verwendung einer Vorrichtung für die Durchführung des Verfahrens nach Anspruch 1, dadurch gekennzeichnet, daß die Vorrichtung aufweist:
eine Energiequelle (12), die so funktionsfähig ist, daß ein gebündelter Energiestrahl (64) emittiert wird;
eine Konstruktion (28), die eine Aufnahmefläche (26) besitzt, auf der ein Teil (52) in schichtartiger Weise hergestellt werden soll;
eine Einrichtung (14) für das dosierte Aufbringen einer Schicht eines sinterfähigen Pulvers (22) auf der Aufnahmefläche (26); und
einen Regler (16), der funktionsfähig ist, um das Ziel des gebündelten Energi strahles (64) so zu führen, daß innerhalb festgelegter Grenzen ein Abschnitt einer jeden Schicht (54, 55, 56, 57) d s Pulvers (22), das auf der Aufnahmefläche (26) dosiert aufgebracht wurde, selektiv gesintert wird;
wobei der Regler (16) so funktionsfähig ist, daß er den Energiestrahl (64) über die Aufnahmefläche (26) führt, um ausgewählte Abschnitte der aufeinanderfolgenden Schichten (54, 55, 56, 57) des Pulvers (22) innerhalb der entsprechenden festgelegten Grenzen in Übereinstimmung mit den aufeinanderfolgenden Querschnittsbereichen eines Teiles zu sintern;
und wobei die Einrichtung für das dosierte Aufbringen (14) so funktionsfähig ist, daß die nachfolgenden Schichten des Pulvers (55, 56, 57) jeweils nach dem selektiven Sintern einer vorangegangenen Schicht (54, 55, 56) dosiert aufgebracht werden, so daß die gesinterten ausgewählten Abschnitte einer der nachfolgenden Schichten mit den gesinterten Abschnitten einer vorangehenden Schicht verbunden werden, um ein Teil (52) herzustellen, das eine Vielzahl von Schichten (54, 55, 56, 57) aufweist, die miteinander gesintert wurden;
und dadurch gekennzeichnet, daß eine Einrichtung (132) für die Steuerung der Temperatur des gesinterten und des nicht gesinterten Pulvers auf der Aufnahmefläche (26) vorhanden ist.

Revendications

1. Procédé de production d'une pièce (52) comprenant les opérations suivantes : déposer une première couche de poudre frittable (22) sur une surface cible (26) ; faire balayer le point d'impact d'un faisceau d'énergie dirigé (64) sur la surface de la cible (26) pour fondre des parties sélectionnées de la première couche (54) de poudre qui correspondent à une première région de la section droite de la pièce (52) en mettant en service le faisceau (64) lorsque le point d'impact du faisceau (64) se trouve à l'intérieur de limite définie par ladite première région de section transversale ;
déposer une seconde couche de poudre frittable (22) sur la première couche (54) ;
faire balayer le point d'impact d'un faisceau d'énergie dirigé (64) sur la surface de la cible (26) pour fritter des parties sélectionnées de la seconde couche (55) correspondant à une seconde région de section transversale de la pièce (52) en mettant le faisceau (64) en service lorsque le point d'impact du faisceau arrive dans des limites définies par ladite région de section transv rsale, d manière que les parti s frittées de la premièr et la seconde couches (54, 55) soient assemblées pendant le

frittag d ladite seconde couche (55) ; et

déposer d'autr s couches succ ssiv s de poudr frittable (22) sur les couches précéd n-tes t fritter un couch d chaque partie successive pour former une pièce (52) constituée par une pluralité de couches frittées (54, 55, 56, 57) ;

caractérisé par :

la commande de la température de la poudre frittée et non frittée sur la surface (26) de la cible.

2. Procédé selon la revendication 1, caractérisé par le fait que les opérations de balayage orientent le point d'impact du faisceau (64) uniquement à l'intérieur des limites respectives des régions de sections transversales correspondantes.

3. Procédé selon la revendication 1, caractérisé en ce que les opérations de balayage et de frittage comprennent encore des opérations de déplacement du point d'impact du faisceau (64) en un balayage de trame (66) et la mise en service et hors service du faisceau (64) pendant le balayage de trame (66) quand le point d'impact est à l'intérieur des limites.

4. Procédé selon la revendication 3, caractérisé par la production du balayage de trame (66) en orientant le faisceau (64) dans une première direction (68) et en réorientant le faisceau (64) de la première direction à une seconde direction (70) pour venir frapper une surface de cible généralement plane.

5. Procédé selon la revendication 3, caractérisé par l'opération de réorientation du faisceau (64) comportant l'utilisation d'une paire de miroirs (46, 47) accouplés à des galvanomètres (48, 49) correspondants, le premier miroir (46) étant décalé pour créer un mouvement du faisceau (64) sur la surface de la cible (26) dans une première direction générale (68), et le second miroir (47) étant décalé pour créer un mouvement du faisceau (64) sur la surface de la cible (26) dans une seconde direction générale (70) perpendiculaire à la première direction (68).

6. Procédé selon la revendication 1, caractérisé par l'imprégnation de la pièce (52) au moyen d'un adhésif.

7. Procédé selon la revendication 1, caractérisé en ce que la poudre (22) est déposée en continu sur la surface de la cible (26).

8. Procédé selon la rev ndication 1, caractérisé par l fait que l'opération d dépôt comprend d s opérations partielles d dépôt d'un tas de poudre (106) à proximité d'un xtrémité (110) de la surface de la cible (102) ; et

de déplacer un tambour tournant en sens inverse (116) de ladite première extrémité (110) à l'autre extrémité (112) de la surface de la cible (102) pour venir en contact avec le tas de poudre et laisser une couche (164) de poudre derrière le tambour mobile (116).

9. Appareil pour appliquer un procédé selon la revendication 1, comprenant :

une source d'énergie (12) utilisable pour émettre un faisceau d'énergie focalisé (64) ;

une structure (28) ayant une surface cible (26) sur laquelle une pièce (52) doit être produite par couches successives ;

des moyens pour distribuer une couche de poudre frittable (22) sur ladite surface de cible (26) ; et

un contrôleur (16) ayant pour objet d'orienter le point d'impact du faisceau d'énergie focalisé (64) pour une opération de frittage sélective à l'intérieur des limites définies d'une partie de chaque couche (54, 55, 56, 57) de poudre (22) répartie sur ladite surface de cible (26),

le contrôleur (16) comprenant un système de balayage (42) pour déplacer le point d'impact du faisceau d'énergie (64) sur ladite surface de cible (26) selon une configuration répétitive (66), et un ordinateur (40) programmé avec les limites définies de chaque couche (54, 55, 56, 57) de la pièce (52) afin de mettre en service le faisceau d'énergie (64) ayant son point d'impact dans les limites définies pour chaque couche (54, 55, 56, 57) alors que le point d'impact du faisceau (64) est déplacé sur la surface de la cible (26), ayant pour objet d'orienter le faisceau d'énergie (64) sur la surface de la cible (26) afin de fritter les parties sélectionnées des couches successives (54, 55, 56, 57) de poudre (22) dans les limites respectives définies correspondant aux régions des sections droites séquentielles d'une pièce ; et

les moyens de distribution (14) ayant pour objet de distribuer des couches successives de poudre (55, 56, 57), chaque couche étant distribuée après le frittage sélectif d'une couche antérieure (54, 55, 56) afin que les parties sélectionnées frittées d l'un des couches successives soient assemblées aux parties frittées d'une couche antérieur , pour produire une pièc (52) comportant un pluralité de couches (54, 55, 56, 57) frittées nsemble ;

l'appareil étant caractérisé par d s moyens (132) pour commander la température d la poudre frittée et non frittée sur la surfac de la cible (26).

10. Appareil selon la revendication 9, caractérisé par le fait que la source d'énergie comprend un laser de manière que le faisceau d'énergie (64) soit un faisceau laser et par le fait que le contrôleur (16) comprend des moyens (42, 44, 35, 38) pour orienter le point d'impact du faisceau laser (64) sur ladite surface de cible (26) et des moyens pour moduler le laser en mettant le faisceau (64) en marche et à l'arrêt afin de fritter sélectivement la poudre (22) sur la surface de la cible (26).

11. Appareil selon la revendication 10, caractérisé par le fait que les moyens d'orientation (42) peuvent agir pour déplacer le point d'impact du faisceau laser (64) selon un balayage de trame (66) de la surface de la cible (26).

12. Appareil selon la revendication 10, caractérisé par le fait que les moyens d'orientation comportent une ou plusieurs lentilles (36, 38) pour focaliser le faisceau laser (64).

13. Appareil selon la revendication 10, caractérisé par le fait que les moyens d'orientation comprennent un prisme (44) pour modifier l'orientation du faisceau laser (64) émis par les moyens à laser (12).

14. Appareil selon la revendication 9, caractérisé par des moyens (132) pour orienter de l'air à température commandée vers la pièce (52) afin de modérer la température de la pièce (52).

15. Appareil selon la revendication 9, caractérisé par le fait que l'ordinateur (40) est capable de déterminer les limites définies des parties sélectionnées de chaque couche (54, 55, 56, 57) de la pièce (52) pour des dimensions hors-tout données de la pièce (52).

16. Appareil selon la revendication 9, caractérisé par le fait que les moyens de distribution de la poudre comprennent une trémie (104) pour recevoir une poudre (106), une sortie doseuse (108), orientant la poudre (106) vers la surface de la cible (102), et un tambour en rotation, en sens inverse (116), se déplaçant en travers de la surface de la cible (102) pour distribuer la poudre (106) sur la surface de la cible (102).

17. Appareil selon la r vendication 9, caractérisé par l fait qu lesdits moy ns d distribution (14) peuvent fonctionner pour distribu r de la poudr de matière plastiqu , d céramiqu , de polymère ou de métaux.

18. Emploi d'un appareil pour appliquer un procédé selon la revendication 1, appareil comprenant :

une source d'énergie (12) susceptible de fonctionner pour émettre un faisceau d'énergie focalisé (64) ;

une structure (28) ayant une surface de cible (16) sur laquelle une pièce (52) doit être formée par couches successives ;

des moyens (14) pour distribuer une couche d'une poudre frittable (22) sur ladite surface de cible (26) ; et

un contrôleur (16) capable de fonctionner pour orienter le point d'impact du faisceau d'énergie focalisé (64) afin de fritter de manière sélective à l'intérieur de limites définies une partie de chaque couche (54, 55, 56, 57) de la poudre (22) distribuée sur ladite surface de cible (26),

le contrôleur (16) ayant pour objet d'orienter le faisceau d'énergie (64) sur la surface de la cible (26) afin de fritter des parties sélectionnées de couches séquentielles (54, 55, 56, 57) de poudre (22) à l'intérieur de limites respectives définies qui correspondent à des régions séquentielles de sections droites d'une pièce ;

les moyens de distribution (14) ayant pour objet de distribuer des couches successives de poudre (55, 56, 57), chacune après le frittage sélectif d'une couche antérieure (54, 55, 56) de manière que les parties sélectionnées frittées de l'une des couches successives soient assemblées à des parties frittées d'une couche antérieure pour former une pièce (52) constituée par une pluralité de couches (54, 55, 56, 57) frittées ensemble ; et caractérisé par des moyens (132) pour contrôler la température de la poudre frittée et non frittée à la surface de la cible (26).

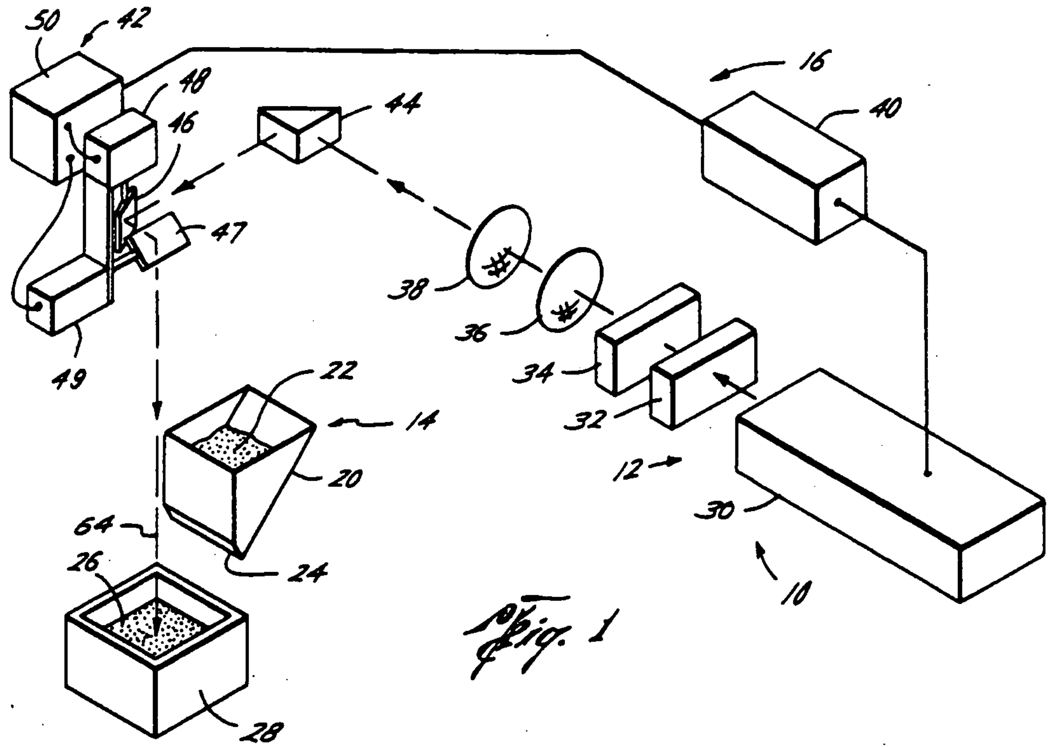
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Fig. 1

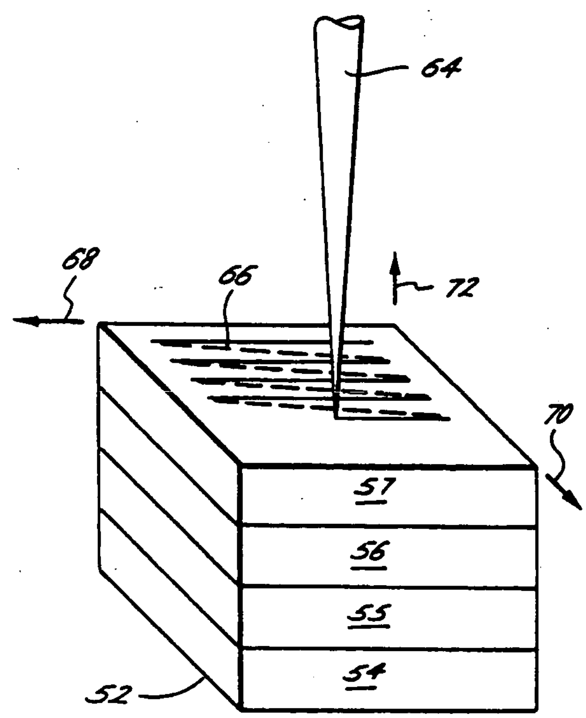
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Fig. 2

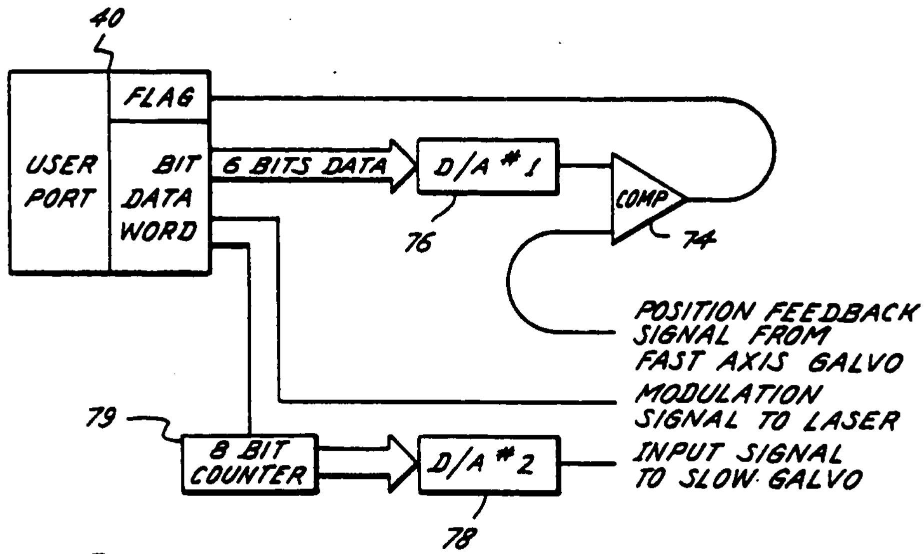
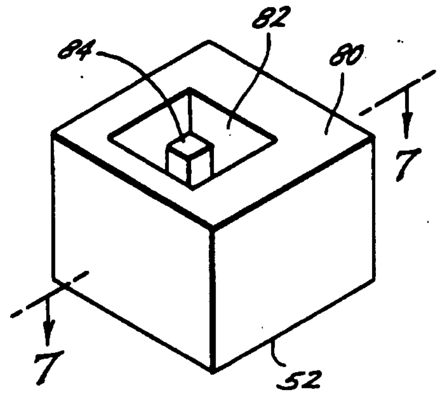


Fig. 3

Fig. 4



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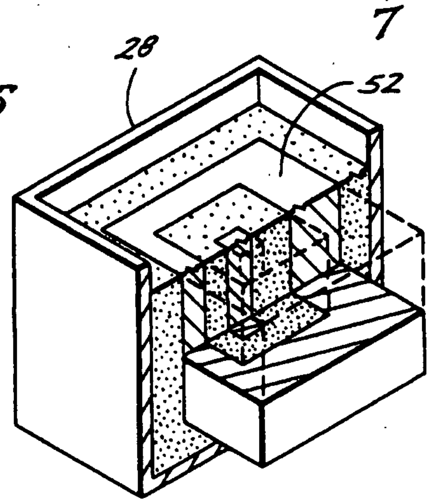

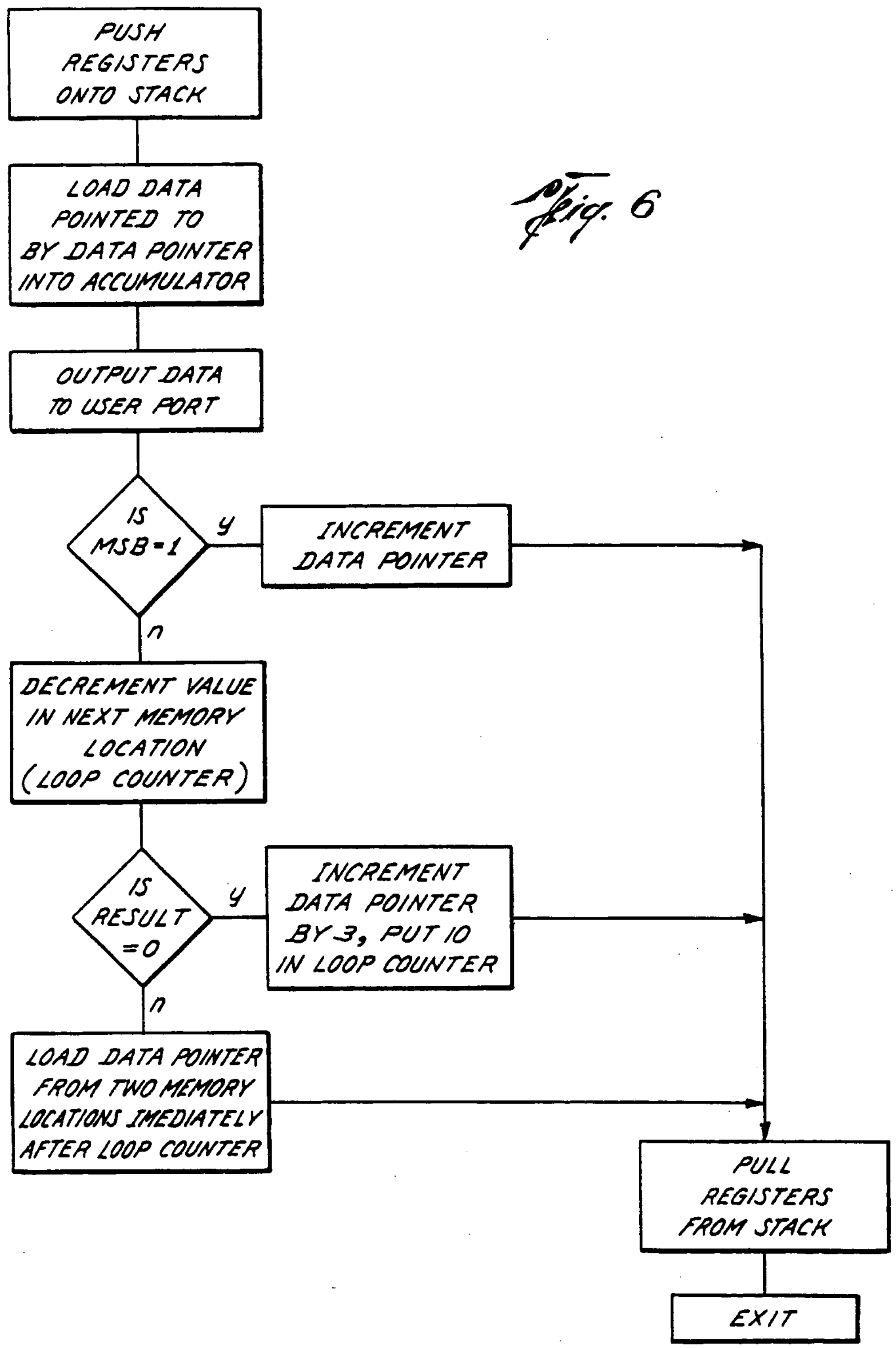
PUSH REGISTERS ONTO STACK
LOAD DATA POINTED TO BY DATA POINTER INTO ACCUMULATOR
OUTPUT DATA TO USER PORT
IS MSB=1
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INCREMENT DATA POINTER
DECREMENT VALUE IN NEXT MEMORY LOCATION (LOOP COUNTER)
IS RESULT =0
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INCREMENT DATA POINTER BY 3, PUT 10 IN LOOP COUNTER
LOAD DATA POINTER FROM TWO MEMORY LOCATIONS IMEDIATELY AFTER LOOP COUNTER
PULL REGISTERS FROM STACK
EXIT

Fig. 6

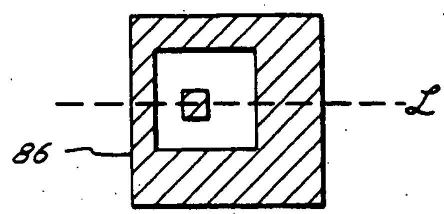


Fig. 7

Fig. 8

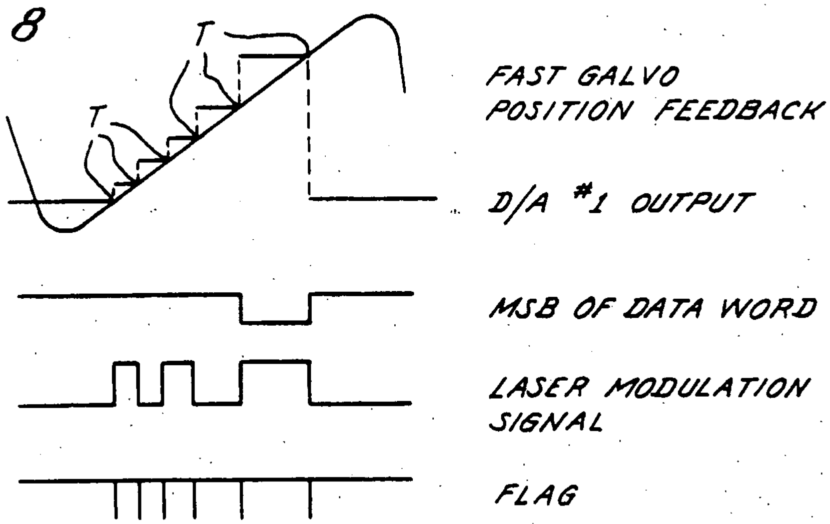
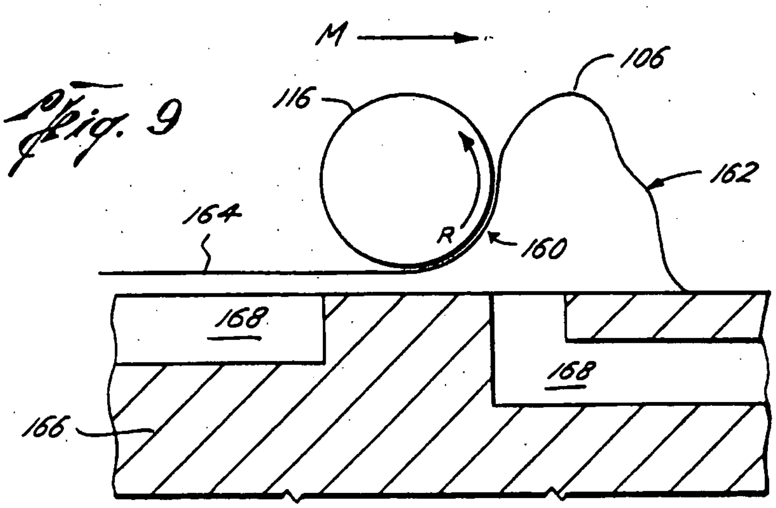


Fig. 9



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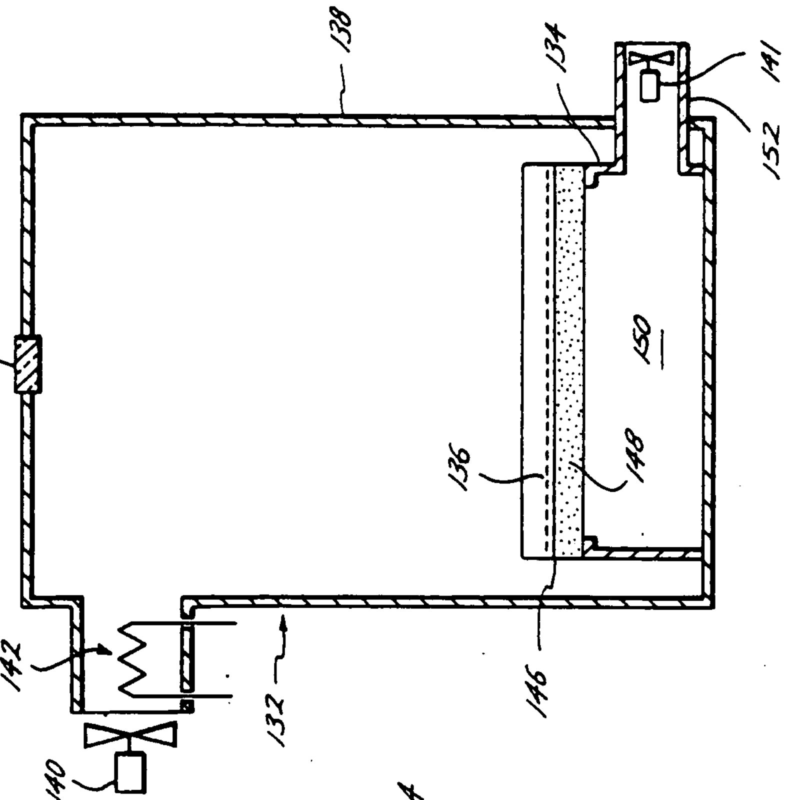
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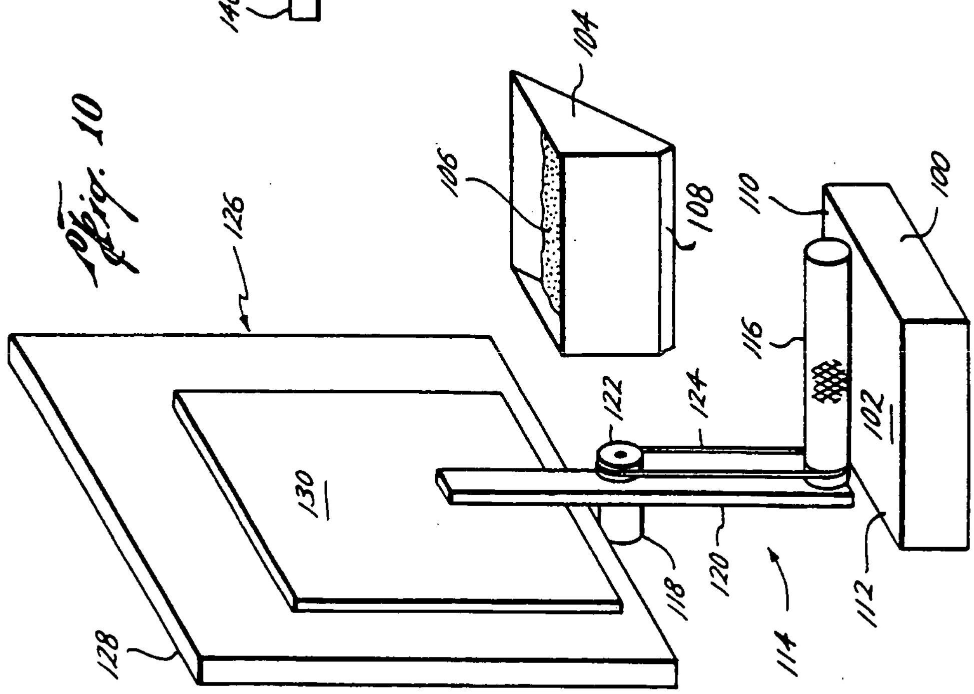
Fig. 10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